INTEGRATED MANAGEMENT OF *FIMBRISTYLIS MILIACEA* (L.) VAHL IN RICE SYSTEMS: SEED ECOLOGY, HERBICIDE SENSITIVITY, AND CROP COMPETITION EFFECTS

XU, W.-D.[1] – LU, Q.[1*] – YAO, Z.-L.[1] – ZHU, J.-W.[2]

[1]*Jiaxing Academy of Agricultural Sciences, Jiaxing 314016, China*

[2]*Ministry of Agriculture and Rural Affairs Key Lab of Molecular Biology of Crop Pathogens and Insects, Department of Plant Protection, Zhejiang University, Hangzhou 310058, China*

**Corresponding author*
e-mail: zhibao208@sina.com

(Received 8th Apr 2025; accepted 11th Jun 2025)

Abstract. This study investigated the biological characteristics of *Fimbristylis miliacea* (L.) Vahl (globe fringerush), a prevalent paddy weed, and evaluated its competitive effects on rice growth to inform targeted control strategies. Seed dormancy patterns were characterized through chemical treatments (Sodium hypochlorite (NaClO), Sodium hydroxide (NaOH), Gibberellic acid (GA_3)) and germination assays under varying soil moisture conditions. Herbicide sensitivity was assessed via pot experiments, while field trials quantified the weed's impact on rice physiology (plant height, tillering, yield) across competition gradients. Results demonstrated that 0.25% NaClO, 0.4% NaOH, and 800 mg/L GA_3 effectively broke seed dormancy, achieving germination rates of 31.70%, 25.07%, and 20.23%, respectively. Optimal germination (89.63%) occurred at 100% soil humidity, but submersion inhibited emergence. The *F. miliacea* population exhibited susceptibility to MCPA dimethylamine salt (ED_{90} = 396.9 g ai/ha), bentazone (314.9 g ai/ha), and propanil (2779.9 g ai/ha), but resistance to triafamone, penoxsulam, florpyrauxifen-benzyl, and benzobicyclon. Increasing weed density progressively reduced rice plant height, effective panicles, and yield, with panicle weight significantly declining at densities > 60 plants/m^2. These findings identify *F. miliacea* as a dormant-seeded species controllable by selective herbicides, while highlighting its yield-limiting competitive effect in rice production systems.
Keywords: *Fimbristylis miliacea, seed dormancy, herbicide sensitivity, weed-rice competition, paddy field, yield loss*

Introduction

Fimbristylis miliacea (L.) Vahl (Cyperaceae), commonly known as globe fringerush, is an annual sedge weed predominantly infesting rice paddies and adjacent levees (Chauhan and Johnson, 2009). As a facultative annual species in paddy fields, which were widely adapted to conditions of direct-seeding of rice (Rao, et al., 2007). In recent decades, shifts in rice cultivation practices—including the widespread adoption of simplified direct-seeding techniques, reduced tillage, and intensive herbicide regimes—had facilitated its rapid expansion across East and Southeast Asia including the Philippines, Thailand, Trinidad, Cambodia, China, Japan, Korea (Begum et al., 2006; Martin et al., 2017). Notably, in northern Zhejiang Province, China, *F. miliacea* had emerged as a dominant weed, causing substantial yield losses due to its high seed production, prolonged emergence window, and adaptability to fluctuating water regimes (Xu et al., 2021a).

To date the morphological characteristics and phenology of *F. miliacea* have been briefly provided in literature. *F. miliacea* flowers all year round and can produce 10000 seeds per plant in the Philippines, which showed that it has the characteristic of

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_79217933

multifertility. Seedling emergence of *F. miliacea* was greatest from seeds placed on the soil surface and seedlings of neither species emerged from seeds buried to depths of >1 cm. This exceptional fecundity endows the weed with strong competitiveness in rice fields, allowing rapid colonization of new production areas shortly after invasion. Notably, the leaves of *F. miliacea* was traditionally used to treat fever (Simpson and Inglis, 2001). The investigating plant *F. miliacea* had been reported to have significant antipyretic and anti-nociceptive activity, antioxidant and antidiarrheal activity, hypoglycemic activity (Roy et al., 2023). While, flooding had a major suppressive effect on emergence and growth of it. Intermittent flooding for 4 of 7 days to a depth of 2 cm effectively controlled growth of *F. miliacea* (Chauhan and Johnson, 2009).

Current understanding of *F. miliacea*'s biological traits remains fragmented. For example, information on methods to break seed dormancy and prompt germination of *F. miliacea* is still relatively limited. Schaedler et al. (2013) demonstrated that resistant biotypes exhibit delayed germination compared to susceptible populations under controlled conditions, yet the role of chemical dormancy-breaking agents (e.g., gibberellic acid) or soil moisture gradients in regulating germination dynamics remains unexplored. Comprehensive characterization of these traits was essential for developing targeted management strategies, as seed bank persistence and emergence patterns directly influence weed competitiveness.

Weeds, in rice field, were considered a major problem by 93% of farmers with 70% of farmers indicating a yield loss of > 20% due to weed competition, and *F. miliacea* was one of the most common weeds in Cambodia (Chhun et al., 2020). Chemical control of *F. miliacea* faces challenges due to evolving herbicide resistance and variable efficacy across regions. Since 1975, phenoxy and synthetic auxins, such as MCPA, 2,4-D, and their isomers, had been extensively utilized in Malaysian rice fields. These herbicides were applied post-emergence across both transplanting and direct-seeding rice ecosystems to manage *F. miliacea* and various sedges and broad-leaved weeds (Watanabe et al., 1996). The first record of incidence of herbicide resistance in Malaysian rice fields was in 1989 with *F. miliacea* (Heap, 2025). This resistant biotype demonstrated survival capabilities when exposed to 2,4-D at doses up to 16 times the recommended level (Watanabe et al., 1997). Nonetheless, the application of 2,4-D and other synthetic auxin herbicides continued in irrigated or rain-fed rice fields in the absence of herbicides as candidates (Ruzmi et al., 2017). Field trials indicated that bentazone alone or combined with carfentrazone-ethyl achieves > 96% control in direct-seeded rice, whereas pyrazosulfuron-ethyl and mefenacet show limited effectiveness (Zhang et al., 2013, 2014). Notably, the performance of newer herbicides such as penoxsulam and benzobicyclon against *F. miliacea* remained unverified, underscoring the urgency for resistance monitoring and mode-of-action diversification in China.

This study systematically investigated three undercharacterized aspects of *F. miliacea* biology: (1) chemical and physical factors governing seed dormancy release and germination, (2) sensitivity gradients to major herbicide classes (ALS inhibitors, synthetic auxins, and photosystem II inhibitors), and (3) interspecific competition impacts on rice growth parameters. By integrating seed ecology, herbicide resistance profiling, and crop-weed interaction analyses, we aim to establish a foundational dataset for optimizing integrated management protocols. Our findings address critical knowledge gaps identified in prior works (Begum et al., 2006; Chauhan and Johnson, 2009). While providing actionable insights for mitigating yield losses in herbicide-intensive rice systems.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_79217933

Materials and methods

Plant materials and chemical substances

Seeds of *F. miliacea* were harvested from naturally infested rice fields in Gutang Village (30°42′10″N, 120°39′20″E), Wangjiangjing Town, Jiaxing City, Zhejiang Province, China, in October 2023. After air-drying, seeds were stored in paper bags at 4°C until experimentation. Chemical dormancy-breaking agents included (NaClO (CAS# 7681-52-9) was bought from Sangon Biotech (Shanghai) Co., Ltd., Shanghai, China. GA_3, (CAS# 77-06-5, ≥ 95% purity) was purchased from Sigma-Aldrich (Shanghai) Trading Co., Ltd., Shanghai, China. NaOH (CAS# 1310-73-2) was purchased from Shanghai Chemical Reagent Co., Ltd., Shanghai, China.

Morphological characterization

Morphological traits of *F. miliacea* (vegetative structures, inflorescences, spikelets, and seeds) were documented across developmental stages during the 2023 rice growing season. A total of 120 *F. miliacea* plants were randomly selected from the field for morphological characterization. Seed and spikelet micromorphology were analyzed using a stereomicroscope (Olympus SZ61) with the magnification of 2×, while macroscopic features were photographed with a digital camera (Canon EOS R6 mark II).

Germination bioassays

Seed dormancy release: Freshly collected seeds were subjected to nine chemical treatments: NaClO concentrations (0.25%, 0.2%, 0.1%), NaOH (0.4%, 0.2%, 0.1%), and GA_3 (1000, 800, 400 mg/L), with deionized water as control. Following 24-h immersion, seeds were rinsed and incubated on moist filter paper in Petri dishes (n≈50 seeds/dish, 3 replicates) at 26~30°C under 12-h photoperiod. Germination (radicle ≥ 3 mm) was recorded daily for 10 days.

Emergence under hydric regimes: In June 2024, seeds were sown in 23-cm-diameter pots containing paddy soil under four moisture conditions: With a soil humidity of 70%, 100%, 2 cm water depth, and 9 cm water depth. The soil used was a silty loam with a pH of 6.6, 1.35% organic matter content, and 0.14% total nitrogen. Soil of each pot amended with 4 g containing 4N-4.2P-11.6K controlled-release fertilizer (STANLEY Co., Ltd., Shandong, China). Soil moisture was monitored using a wireless sensor (TP-WSB-02). For submerged treatments, seeds were enclosed in single-layer gauze and anchored at specified depths. Emergence rates were assessed 10 days post-sowing (3 replicates/treatment). The seeds germinated percentage were calculated as *Equation 1*:

$$\mathrm{GP}(\%) = \frac{\mathrm{GS}}{\mathrm{TNS}} \times 10(\qquad \text{(Eq.1)}$$

where GP is germination percentage, GS is germination seeds, TNS is total numbers of seeds.

Herbicide sensitivity assay

Seeds were germinated in 10-cm plastic pots filled with sterilized substrate in a glasshouse. In each pot, about 60 seeds were sown as per the treatment schedule. The

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_79217933

day temperature recorded inside the glasshouse was 30~32℃. The pots were surface irrigated to maintain the moisture at saturation level. At 5~6 leaf stage, uniform seedlings (40 plants per pot, 4 replicates) were treated with seven herbicide doses (0.03×, 0.1×, 0.3×, 1×, 3×, 9× maximum recommended rates and untreated control) using a bioassay spray tower (3WPSH-500D, spray pressure of 2 kg/m^2 and flow rate of 100 ml/min. Nanjing Agricultural Mechanization Research Institute, China.). Seven herbicides were used and applied in seven treatments (*Table 1*). All herbicides were available in local markets. Aboveground biomass was harvested 20 days after treatment (DAT), and fresh weight inhibition rates (FWIR) were calculated as *Equation 2*:

$$\mathrm{FWIR}(\%) = \frac{\mathrm{FWCP - FWTP}}{\mathrm{FWCP}} \times 100 \qquad \text{(Eq.2)}$$

where FWIR is fresh weight inhibition rate, FWCP is fresh weight of control plants, FWTP is fresh weight of treated plants. Herbicides dose-response data were done using R statistical software with add on package Dose-Response Curve (DRC) and a three-parameter log-logistic model were fitted to the data applying the DRC model fit function described by Mahmood et al. (2016).

$$Y = \frac{D}{1 + \exp[b(\log(x) - \log(ED50 / ED90))]} \qquad \text{(Eq.3)}$$

where *Y* is the fresh weight, x represents herbicide dosage (g ai/ha), D is mean response when herbicide dose is close to zero, ED_{50}/ED_{90} is the dosage (g ai/ha) that reduces fresh weight by 50% or 90% and b is the slope of the curve around ED_{50}/ED_{90}.

Table 1. *Herbicides tested for F. miliacea population sensitivity determination*

Common name	Trade name and a.i. percentage	Recommended dose rates (g ai/ha)	Chemical name	Company information
Florpyrauxifen-benzyl	19% Florpyrauxifen-benzyl SC (Kenshou)	22.8~34.2	Benzyl 4-amino-3-chloro-6-(4-chloro-2-fluoro-3-methoxyphenyl)-5-fluoropyridine-2-carboxylate	Bayer CropScience (China) Co., Ltd.
Penoxsulam	2.5% Penoxsulam OD (Viper)	15~30	2-(2,2-Difluoroethoxy)-6-trifluoromethyl-N-(5,8-dimethoxy[1,2,4]triazolo[1,5-c]pyrimidin-2-yl) benzenesulfonamide	Corteva Agriscience (USA)
Florpyrauxifen	3% Florpyrauxifen EC (Linsco)	18~36	Benzyl 4-amino-3-chloro-6-(4-chloro-2-fluoro-3-methoxyphenyl)-5-fluoropyridine-2-carboxylate	Corteva Agriscience (USA)
Benzobicyclon	25% Benzobicyclon SC (Congfeng)	150~225	3-(2-Chloro-4-mesylbenzoyl)-2-phenylthiobicyclo[3.2.1]oct-2-en-4-one	Nissan Chemical Industries, Ltd. (Japan)
MCPA dimethylamine salt	750 g/L MCPA dimethylamine salt AS (Aohu)	450~562.5	Dimethylamine salt of 2-methyl-4-chlorophenoxyacetic acid	Nufarm Limited (Australia)
Bentazon	480 g/L Bentazon SL (Basagran)	1 080~1440	3-isopropyl-2,1,3-benzothiadiazin-4-one-2,2-dioxide(3-(methylethyl)-(1H)-2,1,3-benzothiadiazin-4(3H)-one2,2-dioxide)	BASF Plant Protection (Jiangsu) Co., Ltd.
Propanil	34% Propanil EC (Kenlingda)	3003.9~4498.2	3’,4’-Dichloropropionanilide	Shandong Cynda Chemical Co., Ltd. (China)

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_79217933

Rice competition study

Field trials were conducted in 2024 in Jiaxing city Zhejiang Province (120°41′24″E, 30°51′55″N) using *Oryza sativa* (Xiushui 14). The temperature range during the experiment was 20 to 32℃ with a 14 h photoperiod. The soil was a brown Clay loam with pH 6.7 and 1.4% organic matter. Controlled-release fertilizer (4N-4.2P-11.6K) was applied at 525 kg/ha before rice sowing. Rice seeds were sown at 60 kg/ha. Seven *F. miliacea* density gradients (0, 40, 80, 120, 160, 200, 240 seeds/m^2) were established in 5 m^2 plots (3 replicates) arranged in randomized complete blocks. At tillering stage, weed densities were adjusted to 0, 1~5, 6~15, 16~25, 26~40, 41~60, and > 61 plants/m^2. Rice growth parameters (plant height, tiller number, grain yield) were measured at maturity from 10 randomly sampled plants/plot. Grain yield was determined from four 0.25 m^2 quadrats/plot.

Statistical analysis

The means and standard deviations of the three biological replicates were calculated using Microsoft Excel 2010. Data were analyzed using Fisher’s Analysis of Variance (ANOVA) technique. Treatment means were compared using the least significant difference (LSD) test at $p \leq 0.05$. Statistical analyses were carried out using the SPSS statistical analytical package (version 21).

Results and analysis

Morphological characteristics

As illustrated in *Figure 1*, *F. miliacea* exhibited distinct morphological features across growth stages. Mature seeds were obovoid (0.5×0.3 mm) with tuberculate surface ornamentation (*Fig. 1A*). Spikelets appeared globose (2~3 mm long), enveloped by gray-brown glumes (*Fig. 1B*). Inflorescences formed compound umbels with terminal spikelets arranged radially (*Fig. 1C*). Seedlings displayed flattened culms (*Fig. 1D, E*), maturing into tufted plants (60~70 cm tall) with linear leaves (*Fig. 1F*). At reproductive stages, dense infestations occupied canopy spaces (*Fig. 1G*), with mature panicles overtopping rice plants (*Fig. 1H*).

Germination and emergence dynamics

Freshly harvested seeds exhibited innate dormancy, showing 4.00% germination under water control (*Table 2*). NaClO (0.25~0.2%) and NaOH (0.4%) effectively broke dormancy, achieving 25.07~31.70% germination ($p < 0.05$). Lower concentrations of NaClO (0.1%) and NaOH (0.2~0.1%) showed limited efficacy (4.30~7.93%). GA_3 at 800 mg/L promoted 20.23% germination, outperforming 1000 mg/L ($p < 0.05$).

Hydric conditions profoundly influenced emergence. Saturated soil humidity (100% FH) yielded 89.63% germination, significantly exceeding 70% FH ($p < 0.05$). Submergence at 2 cm depth reduced germination to 3.93%, while no germination occurred at 9 cm (*Fig. 2*).

Herbicide sensitivity profiles

Dose-response assays revealed marked interspecific variation (*Table 3*). Flucetosulfuron required 423~635 fold recommended doses (14485.2 g ai/ha) to achieve

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_79217933

90% fresh weight inhibition (FWIR), indicating negligible field efficacy. Similarly, penoxsulam (137~275 fold) and florpyrauxifen-benzyl (15~30 fold) exhibited poor control. Benzobicyclon demanded 13.5~20 fold label rates for equivalent suppression. In contrast, MCPA-dimethylamine, bentazone, and propanil achieved > 90% FWIR at ≤ 1 fold recommended doses, confirming population susceptibility.

Figure 1. *Morphological characteristics and field traits of F. miliacea at different growth stages. A: Seeds (Bar = 1 mm); B: Spikelets (Bar = 5 mm); C: Inflorescence (Bar = 5 cm); D, E: Seedling stage (Frontal and lateral views, Bar = 5 cm); F: Mature plant morphology (Bar = 10 cm); G, H: Field infestation symptoms*

Table 2. *Germination rate of F. miliacea under different chemical treatments and concentrations*

Treatments	Concentrations	Germination numbers	Germination rate (%)
NaClO	0.25%	15.67 ± 1.33a	31.70 ± 2.30a
	0.2%	15.67 ± 1.33a	31.63 ± 1.67a
	0.1%	4.00 ± 1.00e	7.93 ± 1.93e
NaOH	0.4%	12.67 ± 0.88b	25.07 ± 2.02b
	0.2%	3.67 ± 0.88ef	7.10 ± 1.64ef
	0.1%	2.33 ± 0.33ef	4.30 ± 0.60f
GA_3	1000 mg/L	8.00 ± 1.00d	16.43 ± 1.99d
	800 mg/L	10.00 ± 1.15c	20.23 ± 2.11c
	400 mg/L	3.33 ± 0.88ef	6.67 ± 1.76ef
Untreated control		2.00 ± 0.58f	4.00 ± 1.15f

Data of germination numbers and germination rate (%) are mean ± standard error. Different lowercase letters within columns indicate significantly different means ($p < 0.05$), the same applies hereafter

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_79217933

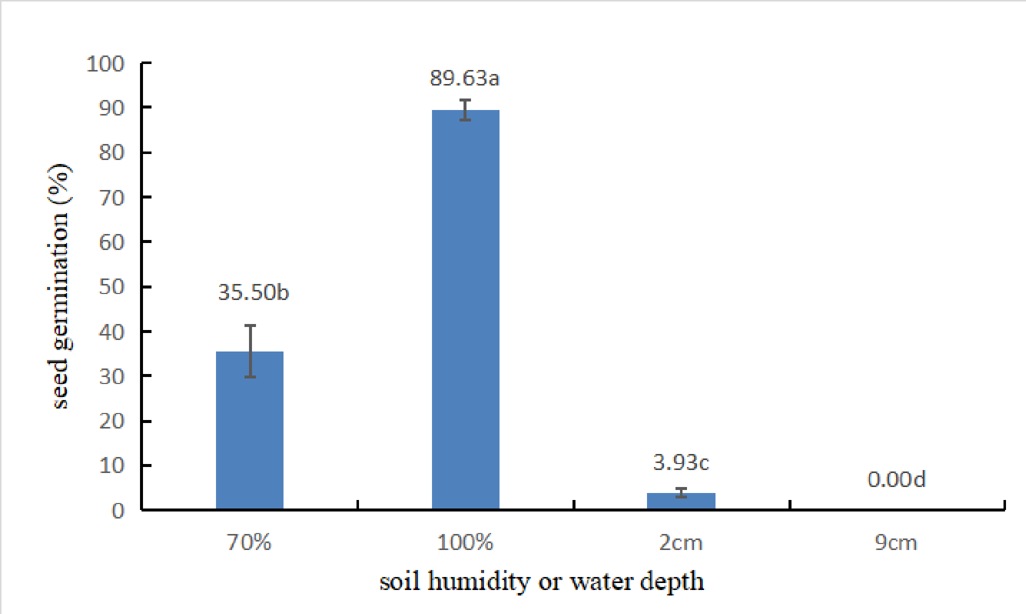

Figure 2. *Effects of different soil humidity or water depths on germination of F. miliacea*

Table 3. *The sensitivity of F. miliacea to different herbicides*

Herbicide	Toxicity regression equation	Correlation coefficient	ED_{50} (g ai/ha)	ED_{90} (g ai/ha)	Recommended dosage (g ai/ha)
Florpyrauxifen-benzyl	Y = 2.1959 + 1.4905x	0.9933	1141.3	14485.2	22.8~34.2
Penoxsulam	Y = 2.7395 + 1.6010x	0.9646	387.3	4125.3	15~30
Florpyrauxifen	Y = 4.1979 + 1.9261x	0.9789	39.1	279.6	18~36
Benzobicyclon	Y = 2.3251 + 1.8726x	0.9728	402.2	3040.0	150~225
MCPA dimethylamine salt	Y = 3.5244 + 2.1936x	0.9733	70.6	396.9	450~562.5
Bentazon	Y = 4.4857 + 1.6332x	0.9963	31.0	314.9	1 080~1440
Propanil	Y = 2.2378 + 1.9432x	0.9814	395.9	2779.9	3003.9~4498.2

Impacts on rice growth

Field competition trials demonstrated density-dependent yield losses (*Table 4*). Compared to the untreated control, most of the treatments of increasing *F. miliacea* density significantly reduced rice plant height, panicle number per plant, and grain yield ($p < 0.05$). Plant height decreased progressively from 86.27 cm to 75.67 cm at the highest density (>61 plants/m^2), with significant differences observed between most density groups. Similarly, panicle number per plant declined sharply from 2.47 to 0.20 in densities ≥ 26 plants/m^2, indicating severe suppression of reproductive growth. Yield loss exhibited a density-dependent response, escalating from 1.88% at 1~5 plants/m^2 to 19.17% at > 61 plants/m^2. Notably, yields at densities ≥ 6 plants/m^2 (720.80 to 618.07 g/m^2) were significantly lower than the control (764.60 g/m^2), with the most pronounced reductions occurring at higher densities (16~25 to > 61 plants/m^2). These results demonstrate that *F. miliacea* competition critically impairs rice growth and productivity, with thresholds as low as 6 plants/m^2 triggering significant yield losses.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_79217933

Table 4. *Effects of different densities of F. miliacea on rice traits in field conditions*

***F. miliacea* density (plants/m^2)**	**Rice plant height (cm)**	**Rice panicles per plant**	**Rice yield (g/m^2)**	**Yield loss rate (%)**
0 (untreated control)	86.27 ± 1.39a	2.47 ± 0.48a	764.60 ± 6.50a	-
1~5	82.73 ± 1.23b	1.67 ± 0.18b	750.33 ± 9.53a	1.88
6~15	80.27 ± 0.77bc	1.27 ± 0.24b	720.80 ± 11.75b	5.73
16~25	79.50 ± 1.47bc	1.87 ± 0.07ab	685.87 ± 5.12c	10.30
26~40	80.33 ± 0.70bc	0.27 ± 0.07c	669.17 ± 5.21c	12.48
41~60	78.33 ± 0.55cd	0.20 ± 0.12c	634.87 ± 8.52d	16.96
>61	75.67 ± 0.70d	0.20 ± 0.20c	618.07 ± 6.87d	19.17

Discussion

Seed dormancy overcoming

The dormancy mechanism ensured that seeds germinate exclusively under optimal environmental conditions, thereby preventing unsuccessful germination in unfavorable settings (Penfield, 2017). Furthermore, dormancy contributes to the formation of a soil seed bank, enabling seeds to sprout at various times or in response to ecosystem disturbances (Rehmani et al., 2022). In this work, the newly collected seeds of *F. miliacea* were subjected to germination induction through soaking in clean water, resulting in a germination rate of merely 4%, which indicated a pronounced dormancy characteristic. Previous studies had demonstrated that seed dormancy could be effectively broken through treatments involving NaClO (Wang et al., 2018), NaOH (He et al., 2016), and GA_3 (Zhang et al., 2024). soaking. For example, the immersion of pyrenes in 0.3 mM GA_3 solution for 24 h enhanced the emergence and survival of plants and the emergence rate index (Medeiros et al., 2015). At the tested concentrations, the germination rates of *F. miliacea* seeds were significantly higher than those of the control group, indicating that the three chemical treatments effectively induced seed dormancy release and stimulated seed germination. Nevertheless, the optimization of the concentrations of the three chemical agents to further enhance the germination rate of *F. miliacea* seeds was not addressed. Additionally, the effects of temperature control and soaking duration on germination rates were not investigated. These aspects require further validation.

The effects of flooding and soil moisture content on seed germination

Previous research on seed flooding has illustrated that a flooding duration showed a clear trend of reduced weed seeds emergence with increasing flooding depth (Smith et al., 1973; Begum et al., 2006). The results of the germination experiments under water-saturated conditions indicated that a soil moisture content of 100% was most conducive to germination, while the presence of a water layer significantly inhibited seed germination. In 2021, our research team investigated the occurrence of weeds in rice fields across different counties and districts in northern Zhejiang, China. The results revealed that the relative dominance of *F. miliacea* in water-seeded rice fields was 2.77 (Xu et al., 2021b), which was higher than that in machine-transplanted fields of 2.34 (Xu et al., 2021a). The seed germination characteristics of *F. miliacea* suggest that the alternating wet and dry conditions in water-seeded fields provide a more suitable habitat for its germination and growth. This finding further supports the conclusion that the

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_79217933

infestation of *F. miliacea* is more severe in water-seeded rice fields compared to machine-transplanted fields.

Sensitivity to different herbicides

The sensitivity of the same weed species to the same herbicide could vary significantly due to factors such as the types of herbicides applied and the duration of their use in different fields. Consequently, weeds of the same species from different regions might exhibit varying levels of sensitivity to the same herbicide (Powles and Yu, 2010). Tracking and monitoring the sensitivity of weeds to different herbicides were of significant importance for achieving effective weed control. Triafamone and Penoxsulam which were categorized as acetolactate synthase (ALS) inhibitors, demonstrating broad-spectrum herbicidal activity against diverse weed species, were sulfonanilide and sulfonylurea herbicides (Fang et al., 2022; Kaur et al., 2024). They were used to control broadleaf weeds and sedges in rice crops. However, their single-site mode of action predisposes weeds to develop resistance under prolonged use. In this study, both herbicides exhibited minimal efficacy against *F. miliacea*, suggesting a plausible emergence of high-level resistance in this weed species to these compounds. Florpyrauxifen-benzyl, a synthetic auxin herbicide (SAH) developed by Dow AgroSciences, Inc., was registered in China in 2017 and has been used as a foliar herbicide to control barnyard grass in paddy fields (Jin et al., 2023). Florpyrauxifen-benzyl exhibits effective herbicidal activity against a wide range of weed species, including *Echinochloa crus-galli*, *Monochoria vaginalis*, *Cyperus difformis*, and *Cyperus iria*, demonstrating a broad-spectrum weed control capability (Jin et al., 2024). In this study, *F. miliace*a exhibited poor susceptibility to florpyrauxifen-benzyl, indicating that this herbicide was not recommended for controlling *F. miliacea* in field conditions. This might be attributed to the potential development of resistance or reduced uptake and translocation of the herbicide in *F. miliacea*. Benzobicyclon is a 4-hydroxyphenylpyruvate dioxygenase (HPPD) inhibitor under registration in the midsouthern United States for control of several annual grasses, sedges, broadleaves, and aquatic weeds in flooded rice (Young et al., 2018). This study demonstrated that *F. miliacea* exhibits low sensitivity to benzobicyclon, suggesting that benzobicyclon was not recommended for controlling *F. miliacea* in field applications too. MCPA-dimethylammonium is a hormone-type, selective, systemic herbicide, readily absorbed by roots and leaves, used for controlling annual and perennial weeds in grassland, cereals, turf, as well as aquatic broadleaf weeds (Niaz et al., 2023). In this study, *F. miliacea* exhibited high sensitivity to MCPA-dimethylammonium, and effective control was achieved within the recommended dosage range, which is consistent with the findings reported by Ruzmi et al. (2017). Bentazon is a PSII inhibitor and is primarily a post emergence herbicide used for selective control of broadleaf weeds in crop production, such as for soybean [*Glycine max* (L.) Merr.], rice, corn (*Zea mays* L.), and peanut (*Arachis hypogaea* L.) (Zhu et al., 2009). In practical applications, bentazon is commonly formulated in combination with MCPA and carfentrazone-ethyl for controlling broadleaf and sedge weeds in crop fields. In this work, the tested *F. miliacea* population exhibited high sensitivity to bentazon. Effective control of this weed can be achieved by applying a bentazon-based herbicide mixture at the appropriate timing before the tillering stage of rice. Propanil is an inhibitor of the photosystem-II, which was a common herbicide used for the management of *E. crus-galli* in rice paddies (Damalas and Koutroubas, 2023). This study showed that the *F. miliacea* population

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_79217933

demonstrated sensitivity to propanil. To achieve optimal control efficacy in field applications, it was essential to ensure thorough coverage of the plants with the herbicide solution. In summary, among the herbicides selected for chemical control, the combination of MCPA and bentazon are the optimal choice. Additionally, when controlling other weeds in rice fields, such as barnyardgrass, the use of propanil can simultaneously manage *F. miliacea*.

Impact on rice growth

In global rice cultivation systems, phytophagous competition accounts for approximately 35% of yield attenuation, significantly surpassing the cumulative phytopathological impacts of invertebrate herbivores, ascomycete fungi, and gram-negative bacterial pathogens (Oerke and Dehne, 2004). As a common weed in rice fields, *F. miliacea* shared general harmful characteristics typical of weeds. It competed for space in rice paddies, and as its field density increases, the inhibition of various physiological indicators of rice became more pronounced. In production fields, high infestation levels of *F. miliacea* resulted in significant yield losses (Schaedler et al., 2015). The previous study by Baghestani et al. (2007) indicated that the highest maize yield and leaf area index (LAI) losses were observed at simultaneous emergence of weed and maize resulted in 85 and 92% yield loss and 73 and 53% LAI loss in the first and second years of experiments, respectively. Hirani et al. (2024) showed that weed interference up to crop harvest lowered the green gram dry matter accumulation by 34.11%, seed index by 8.98%, grain yield by 76.21% and biological yield by 31.06%. The plant height, productive panicles per plant, and grain yield of rice exhibited a gradual decline with increasing weed density under *F. miliacea* infestation in this present study. Notably, when the weed density exceeded 60 plants/m^2, the number of grains per panicle was significantly reduced. To mitigate substantial yield losses in rice production, control measures should be implemented once the weed density surpasses 5 plants/m^2.

Conclusions

This study demonstrated that *F. miliacea* control requires an integrated approach combining chemical and cultural methods. The weed's seed dormancy could be effectively broken by 0.25% NaClO, 0.4% NaOH or 800 mg/L GA_3, with optimal germination (89.63%) occurring under saturated soil conditions. For chemical control, MCPA dimethylamine salt (ED_{90} 396.9 g ai/ha), bentazone (314.9 g ai/ha) and propanil (2779.9 g ai/ha) showed high efficacy, while resistance was observed to other herbicides. Field trials revealed that rice yield components (plant height, panicle number and grain weight) were significantly reduced at weed densities > 60 plants/m^2. These findings suggested that effective management should combine: 1) targeted herbicide applications using susceptible chemicals, 2) water management to maintain flooding conditions that inhibited weed germination, and 3) early intervention before weed populations reach threshold levels that impact rice yield. This integrated strategy provides a practical framework for *F. miliacea* control in rice production systems.

Funding. This work was supported by Science and Technology Program Project of Jiaxing City (2025CGZ067), Zhejiang Province "San Nong Jiu Fang" Science and Technology Collaboration

Program(2025SNJF004), Science and Technology Program Project of Zhejiang Province (2022C02035), Agricultural Science and Technology Park Construction Project of Gaoqiao Tongxiang(2021E70009).

REFERENCES

[1] Baghestani, M. A., Zand, E., Soufizadeh, S., Agha, B., M. (2007): Evaluation of different empirical models of crop/weed competition to estimate yield and LAI losses from common lambsquarters (*Chenopodium album* L.) in maize (*Zea mays* L.). – Pakistan Journal of Biological Sciences 10: 3752-3761.

[2] Begum, M., Juraimi, A. S., Amartalingam, R., Man, A. B., Rastan, S. O. B. S. (2006): The effects of sowing depth and flooding on the emergence, survival, and growth of *Fimbristylis miliacea* (L.) Vahl. – Weed Biology and Management 6: 157-164.

[3] Chauhan, B. S., Johnson, D. E. (2009): Ecological studies on *Cyperus difformis*, *Cyperus iria* and *Fimbristylis miliacea*: three troublesome annual sedge weeds of rice. – Annals of Applied Biology 155: 103-112.

[4] Chhun, S., Kumar, V., Martin, R. J., Srean, P., Hadi, B. A. R. (2020): Weed management practices of smallholder rice farmers in Northwest Cambodia. – Crop Protection 135: 104793.

[5] Damalas, C. A., Koutroubas, S. D. (2023): Herbicide-resistant barnyardgrass (*Echinochloa crus-galli*) in global rice production. – Weed Biology and Management 23: 23-33.

[6] Fang, J., Yang, D., Zhao, Z., Chen, J., Dong, L. (2022): A novel Phe-206-Leu mutation in acetolactate synthase confers resistance to penoxsulam in barnyardgrass (*Echinochloa crus-galli* (L.) P. Beauv). – Pest Management Science 78: 2560-2570.

[7] He, X. Q., Wang, Y. R., Hu, X. W., Baskin, C. C., Baskin, J. M., Lv, Y. Y. (2016): Seed dormancy and dormancy-breaking methods in *Leymus chinensis* (Trin.) Tzvel. (Poaceae). – Grass and Forage Science 71: 641-648.

[8] Heap, I. (2025): The International Survey of Herbicide Resistant Weeds. – Online. Available: http://www.weedscience.org.

[9] Hirani, A. K., Korav, S., Rajanna, G. A., Elansary, H. O., Mahmoud, E. A. (2024): Determination of critical crop-weed competition period: impact on growth, nutrient dynamics and productivity of green gram (*Vigna radiata*). – Heliyon 10: e36855.

[10] Jin, W. Y., Sun, J. Q., Tang, W., Yang, Y. J., Zhang, J. P., Lu, Y. L., Yu, X. Y. (2023): Comparative transcriptome analysis of the differential effects of florpyrauxifen-benzyl treatment on phytohormone transduction between florpyrauxifen-benzyl-resistant and -susceptible barnyard grasses (*Echinochloa crus-galli* (L.) P. Beauv). – Agronomy 13(3): 702.

[11] Jin, W. Y., Xie, K. X., Tang, W., Yang, Y. J., Zhang, J. P., Yu, X., Lu, Y. L. (2024): Comparative metabolomics and transcriptomics provide new insights into florpyrauxifen-benzyl resistance in Echinochloa glabrescens. – Frontiers in Plant Science 15: 1392460.

[12] Kaur, P., Kaur, R., Kaur, H., Bhullar, M. S. (2024): Understanding environmental fate: soil variability and rainfall influence on triafamone and ethoxysulfuron leaching. – Bulletin of Environmental Contamination and Toxicology 113: 25.

[13] Mahmood, K., Mathiassen, S. K., Kristensen, M., Kudsk, P. (2016): Multiple herbicide resistance in Lolium multiflorum and identification of conserved regulatory elements of herbicide resistance genes. – Frontiers in Plant Science 7: 1160.

[14] Martin, R. J., Van Ogtrop, F., Henson, Y., Broeum, K., Rien, R., Srean, P., Tan, D. K. (2017): A survey of weed seed contamination of rice paddy in Cambodia. – Weed Research 57: 333-341.

[15] Medeiros, M. J., Oliveira, M. T., Willadino, L., Santos, M. G. (2015): Overcoming seed dormancy using gibberellic acid and the performance of young Syagrus coronata plants

under severe drought stress and recovery. – Plant Physiology and Biochemistry 97: 278-286.
[16] Niaz, A., Spokas, K. A., Gámiz, B., Mulla, D., Arshad, K. R., Hussain, S. (2023): 2-Methyl-4-chlorophenoxyacetic acid (MCPA) sorption and desorption as a function of biochar properties and pyrolysis temperature. – Plos One 18: e0291398.
[17] Oerke, E. C., Dehne, H. W. (2004): Safeguarding production—losses in major crops and the role of crop protection. – Crop Protection 23: 275-285.
[18] Penfield, S. (2017): Seed dormancy and germination. – Current Biology 27: R853–R909.
[19] Powles, S. B., Yu, Q. (2010): Evolution in action: plants resistant to herbicides. – Annual Review of Plant Biology 61: 317-347.
[20] Rao, A. N., Johnson, D. E., Sivaprasad, B., Ladha, J. K., Mortimer, A. M. (2007): Weed management in direct-seeded rice. – Advances in Agronomy 93: 153-255.
[21] Rehmani, M. S., Aziz, U., Xian, B., Shu, K. (2022): Seed dormancy and longevity: a mutual dependence or a trade-off? – Plant Cell Physiology 63: 1029-1037.
[22] Roy, R., Liya, I. J., Roy, J., Basher, M. A. (2023): Acute and subchronic toxicity profile of methanol extract of leaves of *Fimbristylis miliacea* (L.) Vahl. – Toxicology Reports 10: 301-307.
[23] Ruzmi, R., Ahmad-Hamdani, M. S., Bakar, B. B. (2017): Prevalence of herbicide-resistant weed species in Malaysian rice fields: a review. – Weed Biology and Management 17: 3-16.
[24] Schaedler, C. E., Noldin, J. A., Agostinetto, D., Dalmagro, T., Fontana, L. C. (2013): Germination and growth of *Fimbristylis miliacea* biotypes resistant and susceptible to acetolactate synthase-inhibiting herbicides. – Planta Daninha 31: 687-694.
[25] Schaedler, C. E., Burgos, N. R., Noldin, J. A., Alcober, E. A., Salas, R. A., Agostinetto, D. (2015): Competitive ability of ALS-inhibitor herbicide-resistant *Fimbristylis miliacea*. – Weed Research 55: 482-492.
[26] Simpson, D. A., Inglis, C. A. (2001): Cyperaceae of economic, ethnobotanical and horticultural importance: a checklist. – Kew Bulletin 56: 257-360.
[27] Smith, R. J., Fox, W. T. (1973): Soil water and growth of rice and weeds. – Weed Science 21: 61-63.
[28] Wang, L., Du, Y., Rahman, M. M., Tang, B., Fan, L. J., Kilaru, A. (2018): Establishment of an efficient in vitro propagation system for Iris sanguinea. – Scientific Reports 8: 17100.
[29] Watanabe, H., Azmi, M., Ismail, Z. M. (1996): MARDI/MADA/JIRCAS Collaborative Study (1992-1996). – Malaysian Agricultural Research and Development Institute, Serdang.
[30] Watanabe, H., Ismail, Z. M., Ho, N. K. (1997): Response of 2,4-D resistant biotype of *Fimbristylis miliacea* (L.) Vahl. to 2,4-D dimethylamine and its distribution in Muda plain, Peninsular Malaysia. – Journal of Weed Science and Technology 42: 240-249.
[31] Xu, W. D., Li, G., Li, J., Lu, Q. (2021a): Weed community structure and characterization of machine-transplanted paddy fields in areas of rice-wheat rotation in northern Zhejiang Province, China. – Applied Ecology and Environmental Research 19: 3097-3114.
[32] Xu, W. D., Li, J., Lu, Q., Wang, Y. Q. (2021b): Weed community composition and difference of diversity in wet direct-seeding paddy fields in rice-wheat rotation areas in northern Zhejiang province, China. – Journal of Ecology and Rural Environment 37: 57-64 (in Chinese).
[33] Young, M. L., Norsworthy, J. K., Scott, R. C., Bond, J. A., Heiser, J. (2018): Benzobicyclon as a post-flood option for weedy rice control. – Weed Technology 32: 371-378.
[34] Zhang, D. L., Shen, X. F., Chen, Y. (2013): Sedge and broadleaf weed control effects of bentazone. Carfentrazone-ethyl 40% WG in direct seeding paddy fields. – Agrochemicals 52: 761-764 (in Chinese).

[35] Zhang, D. L., Shen, X. F., Chen, Y. (2014): The test of mefenacet. Pyrazosulfuron-ethyl. Alachlor 31% EA for control of annual weeds in paddy field. – Agrochemicals 53: 214-216 + 233 (in Chinese).
[36] Zhang, L. H., Tang, Q. Y., Li, P. W., Li, C. Z., Jiang, L. J., Chen, J. Z., Chen, Y. Z., Liu, Q., Yang, Y. (2024): Methodological and physiological study during seed dormancy release of Symplocos paniculata. – Plants 13: 1459.
[37] Zhu, J., Patzoldt, W. L., Radwan, O., Tranel, P. J., Clough, S. J. (2009): Effects of photosystem-II-interfering herbicides atrazine and bentazon on the soybean transcriptome. – Plant Genome 2: 191-205.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2304_79217933